Simulation Analysis of Low PAPR FFT-based OFDM Through Nakagami Channel

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***Abstract* — In response to the inefficiency of power amplifier in conventional Orthogonal Frequency Division Multiplexing (OFDM) system, a low Peak-to-Average Power Ratio (PAPR) scenario can be obtained by implementing several PAPR reduction techniques. Partial Transmit Sequence (PTS) is a well-known instance to provide zero distortion for the system, while clipping is one of the simplest methods but it is sacrificing the error rate performance. In this work, Authors focused on analyzing the implementation of PTS and Palm Date Leaf clipping technique on OFDM system with 16-, 64-, 256-, and 1024-QAM under various Nakagami channel. In addition, the High-Power Amplifier (HPA) was also considered by using Solid State Power Amplifier (SSPA) model. It was found that linear HPA serves as the lower boundary for non-linear HPA, and system under high saturation level performs similarly. In physical properties, high saturation level is equivalent to higher power consumption in amplifier. Thus, optimal level was obtained by considering taking the one with moderate BER performance. After the system's PAPR was reduced, the optimum saturation level of HPA was found to be 5 dB, 8 dB, 9 dB, and 11 dB for each Quadrature Amplitude Modulation (QAM) under Nakagami channel with *m* value of 1.5. However, this value was found to be ample for lower *m* value such as 1 or 0.7. In this case, the system required lower saturation level on the HPA for Nakagami channel with lower *m* value.**

Keywords* — *BER, Nakagami, PTS, Clipping, SSPA

I. Introduction

Wireless communication is no doubt one instance that is growing at fastest rate in communication sector. The ability to send information as an electromagnetic signal over the air has been able to capture the attention of many people [1], [2]. However, the communicating parties may not be in a Line of Sight (LOS) circumstance. The transmitted signal will subsequently be scattered, reflected, or go through any other process.

Due to this phenomenon, the transmitted signal may be degraded significantly, such that the receiver will not be able to retrieve the original information. In response to this, Orthogonal Frequency Division Multiplexing (OFDM) has been proposed [3].

Regardless of the merits, this method does have disadvantages. One of the most significant problem arises from the power perspective, where the addition of several signals of different frequencies could form a high peak in a certain point. This peak is significant compared to average value of the signal [4]. Practically, Peak-to-Average Power Ratio (PAPR) is a term used to describe the ratio between the peak value of the signal with its average. However, a CCDF plot is normally made for its evaluation by taking the ratio of all part of the signal with its average. In physical representation, higher value widens the operation range of High-Power Amplifier (HPA). Due to this, there are two options. First one is amenably extending the range of HPA to have perfect amplification of the signal. In this case, the device will consume more power, thus making it inefficient for mobile devices with limited power source. Otherwise, the signal will not be amplified perfectly, thus making it to be distorted and making some parts of it unable to be recovered by the receiver side.

In the approach of lowering the PAPR, several techniques have been proposed. The simplest method is to clip the signal. Palm Date Leaf clipping (PDL) is one version that has been proven to be superior to some other clipping methods [5]. Another instance is Partial Transmit Sequence (PTS), which is a well-known technique capable of providing zero distortion to the signal [6]–[9]. Its performance can be improved by having Particle Swarm Optimization (PSO) algorithm, especially to speed up the process [10]–[12].

Authors in [6], [7] have analyzed the performance of the combination of two PAPR lowering techniques mentioned above, but over NLOS Rayleigh fading channel only, and without HPA. In this work, Authors extended the analysis to a more general fading channel with Nakagami fading. Theoretically, it can cover Rician and Rayleigh fading with proper parameter adjustment, while presenting a better approach for both distribution at the same time [13]–[15]. In addition, the HPA is modelled with Solid State Power Amplifier (SSPA). So, this work covers the analysis of HPA usage for OFDM system through Nakagami channel.

The remainder of this paper is organized as follow. Chapter II focuses on brief survey on the PAPR reduction techniques. Next, Chapter III elaborates the proposed system to be analyzed, including its block diagram and the parameters. The result is discussed in Chapter IV. Finally, the conclusion is drawn in Chapter V.

II. PAPR Reduction Techniques

This chapter has three sections, each to briefly survey one PAPR reduction technique. The first one is PTS technique. Finally, the PDL clipping is also surveyed.

A. Partial Transmit Sequence

Even though combination of multiple frequencies does not interfere each other, in-phase components could form a high peak. This in turn will increase the PAPR value.

To lower it down, PTS technique divides the signal X into V sub-blocks, then rotate it by a phase factor (b_V), then combine it once again. To simplify the process, the phase factor is usually confined to several values such as π/2, π, and 3π/2. Since now the signal has been rotated, its PAPR is hoped to be lowered. The process will be looped until all possible events are done, then the one with lowest PAPR will be chosen to be transmitted along with the phase factor corresponding to it as a Side Information (SI) [10], [12], [16].

B. Palm Date Leaf Clipping

Clipping technique requires a Clipping Ratio (CR), which defines the ratio of signal's amplitude's limit and the RMS value of it. The process will have the input signal multiplied by a certain scaling factor for the part that exceeds the limit.

In PDL clipping technique, the scaling factor is defined in (1). This type requires a smoothness factor β to determine how worse the clipping will be. A good performance is achieved when it is set to be 5 [5]. In addition, having PTS implemented in the system alongside with PDL is proven to be able to lower the PAPR. It was found that PTS provides best improvement to PDL technique at CR of 7 dB, where it manages to provide close BER performance to the higher CR values while reducing PAPR at the same time [7].

$$P_{\beta}^{A}(r) = \frac{A}{\cosh\left(\frac{r-A}{\beta}\right)} \tag{1}$$

III. SIMULATION DESIGN

This chapter discusses the design for the simulation analysis conducted in this work. The discussion has two sections. The first one focuses to the block diagram of the system, then followed with the parameters used in the simulation.

Fig. 1 shows the block diagram of the system. It starts by generating bit stream as the information, which then is bit-modulated. Next, the signal is transformed from frequency into time domain, i.e., IFFT. After that, it is partitioned into several sub-blocks for PTS technique, then the result is clipped. Here, the processed signal is evaluated for its PAPR. Then, it is simulated over HPA, before then transmitted over wireless channel. Upon received, it has the PTS undone, then is transformed back into frequency domain, i.e., using FFT. After that, the signal is demodulated back into bit stream, and the received bit is compared with the original one to evaluate the BER performance. In addition, the solid arrow shows physical connection between blocks, while dashed line represents wireless connection in the system.

For the simulation, several parameters are set to be analyzed. The system allocates 64 sub-carriers, where 48 of them are carrying data, 16 are allocated for null carriers, and Cyclic Prefix (CP) is set to take another 16. Along with it, it has 1000 OFDM symbols and 20 MHz of bandwidth to be analyzed within the simulation. The PTS technique is focused to 8 sub-blocks, while the PDL clipping has smoothness factor of 5. The HPA is modeled with SSPA, with saturation level of 5 dB and nonlinearity level of 1. The wireless transmission is modelled with Nakagami fading channel with several *m* values, i.e., 0.7, 1.0, and 1.5. These values are summarized within Table I.

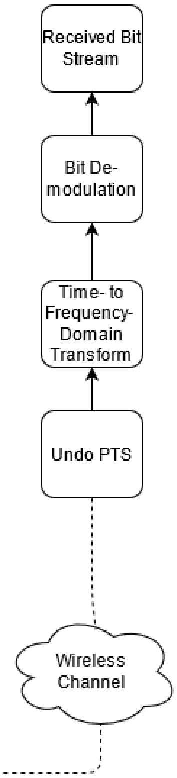

Fig. 1. Simulation block diagram

TABLE I. SIMULATION PARAMETERS

Parameter	Value
Sub-carrier	64
OFDM Symbol	1000
Bit Modulation (QAM)	16; 64; 256; 1024
Bandwidth	20 MHz
PTS sub-block	8
Smoothness factor	5
Clipping Ratio	7 dB
HPA model	SSPA
HPA's Level of Nonlinearity (*p*)	1
HPA's Saturation level (*A*)	3 – 13 dB
Nakagami (*m*)	0.7; 1.0; 1.5

The simulation analysis is done to evaluate the performance of conventional OFDM system which implements FFT, and reinforced by PTS and PDL as PAPR reducer. It focuses in analyzing two parameters, i.e., BER and PAPR of the system. The first analysis is done for PAPR performance, then followed by the BER performance analysis. The PAPR is analyzed based on Complementary Cumulative Distribution Function (CCDF) plot, where all part of the signal is to be divided with the overall average of it, then the distribution is plotted. Finally, the BER analysis starts by tuning the HPA to see how the system performs under various conditions. Specifically saying, it is done under Nakagami channel at *m* of 1.5. After the optimal performance is achieved, the analysis is then extended to cover various *m* value to evaluate system.

IV. RESULT AND DISCUSSION

This chapter has two sections. The first one discusses the PAPR performance by using CCDF plot. Next to it, the effect of various parameters of HPA is discussed by analyzing the BER performance. Its result is then used for the final evaluation of BER performance over various *m* values of Nakagami channel. To have a better understanding, the BER performance is also presented as a comparison between conventional OFDM and the PAPR-reduced system, where both systems use the HPA's parameter as discussed previously.

Fig. 2 shows the CCDF plot of multiple QAM used in this work. Note that this graph took the signal right before it entered the HPA, thus making it independent to the parameters of the amplifier. In addition, the PAPR is evaluated after the signal went through PTS and PDL clipping technique.

All four systems had approximately 2% part of the signal having PAPR higher than 5 dB. The system with 16-QAM had highest PAPR at 5.9697 dB, even though only 0.01% part of the signal was included in this area. As for 64-QAM, the highest value was found at 5.8989 dB –which is lower than 16-QAM– but 0.4% part of the signal was included in this area. In the case of 256-QAM, the highest PAPR was 6.0665 dB, covering only 0.04% part of the signal. Finally, 1024-QAM had highest PAPR at 6.0573 dB, covering 0.05% part of the signal.

Both PAPR reduction techniques were able to lower the PAPR of conventional OFDM. Even though higher QAM still has higher PAPR, the difference is not significant, and the average of PAPR in these scenarios are found to be 6 dB.

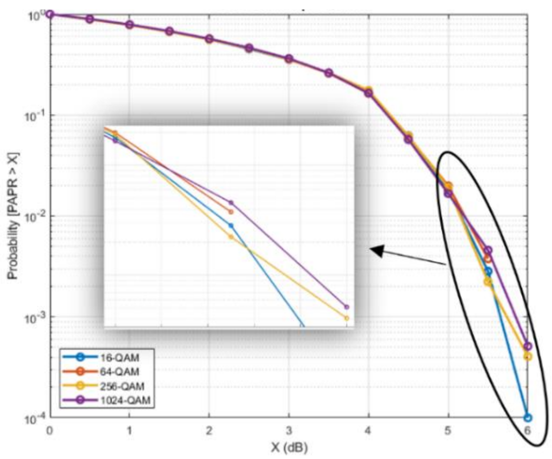

Fig. 2. CCDF plot for 16-QAM, 64-QAM, 256-QAM, and 1024-QAM

Next, the effect from various values in HPA's parameters are elaborated. The analysis was based on BER performance. Fig. 3 shows the evaluation on 16-QAM. It was found that as saturation level gets close to 7 dB, the BER performance is close to linear HPA. In fact, the performance under 5 dB is able to get close to the ideal condition.

Next, Fig. 4 shows the evaluation for 64-QAM. In this case, the linear HPA condition was approached as saturation level gets as high as 8 dB.

Fig. 5 shows the evaluation for 256-QAM. The graph shows that the performance under saturation level of 9 dB, 10 dB, and 11 dB are similar.

Fig. 6 shows the evaluation for 1024-QAM. In this case, the performance under saturation level of 11 dB, 12 dB, and 13 dB are close to each other.

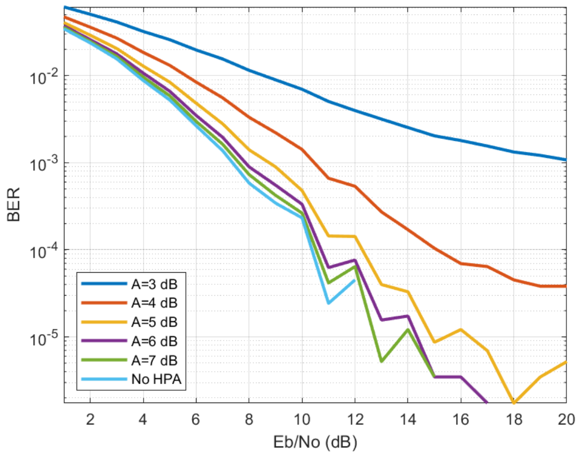

Fig. 3. BER performance of 16-QAM under various saturation level

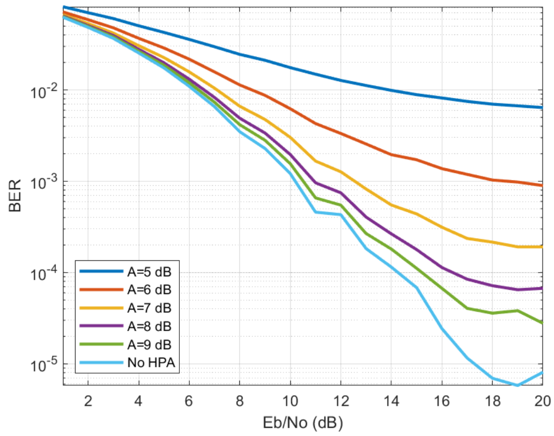

Fig. 4. BER performance of 64-QAM under various saturation level

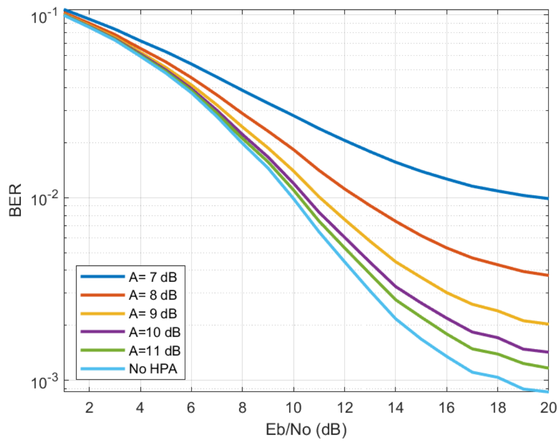

Fig. 5. BER performance of 256-QAM under various saturation level

For all scenarios, higher saturation level always approaches linear HPA condition. However, the performance under ideal HPA serves as the lower bound, thus non-linear HPA may only get close to it without exceeding the boundary. Interestingly, there was no significant improvement to the performance even if the saturation level was increased. At the same time, higher saturation level would be unnecessary since it only decreases the efficiency of the HPA by consuming more power without providing significant improvement to the performance. Thus, the optimal saturation level for each QAM was obtained when a moderate BER performance of it was achieved. Table II briefly summarizes the highest PAPR on each QAM along with the corresponding optimal saturation level.

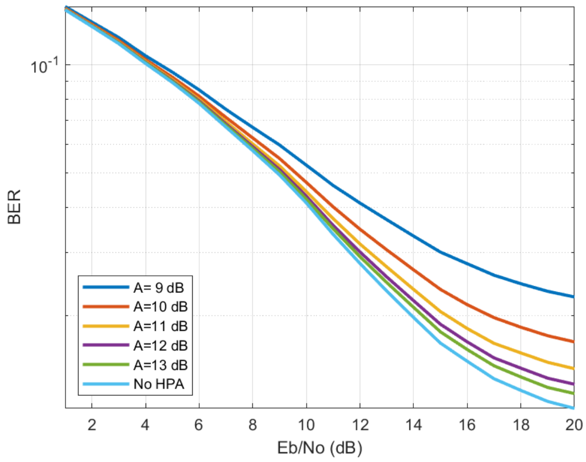

Fig. 6. BER performance of 1024-QAM under various saturation level

TABLE II. HIGHEST PAPR AND OPTIMAL SATURATION LEVEL OF VARIOUS QAM

QAM	PAPR (dB)	A (dB)
16	5.9697	5
64	5.8989	8
256	6.0665	9
1024	6.0573	11

Next, by knowing the optimal saturation level on each QAM, the BER performance is once again evaluated. In this case, each QAM was evaluated under various Nakagami channels, and each of them implemented the optimal HPA parameter. In fact, setting *m* to 1 lets Nakagami to resemble Rayleigh fading channel, while higher *m* makes it resemble Rician fading channel. It is expected to have worst performance under lowest *m* value, and best one under the highest value. In addition, each scenario was compared to the ideal HPA condition.

Fig. 7 shows the evaluation for 16-QAM. As expected, the performance gets better as *m* was increased. For the comparison to the ideal HPA, the system performs very close to it at *m* of 0.7. Meanwhile, the difference between the non-linear and ideal HPA could be seen starting from *m* of 1. At *m* of 1.5, the difference was more obvious compared to the previous values. In this case, the optimal saturation level for 16-QAM can be lowered (e.g., to 4 dB) for lower *m* values of Nakagami channel.

Fig. 8 shows the evaluation of 64-QAM. Similarly, the BER performance was worst at lowest *m*. For the value of 0.7, the non-linear system was very close to the ideal condition. Similar to 16-QAM, the difference got bigger as *m* was increased.

Fig. 9 shows the evaluation of 256-QAM. In this case, the non-linear system performed closely to the ideal condition at low *m*. Interestingly, the difference between the two conditions got more significant as *m* was increased.

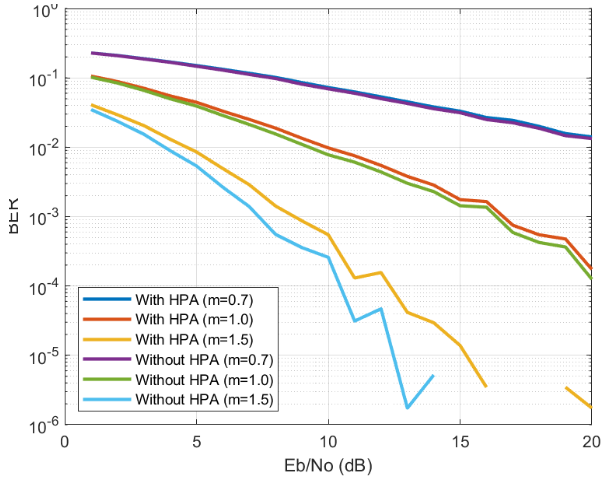

Fig. 7. BER performance of 16-QAM under various Nakagami channel

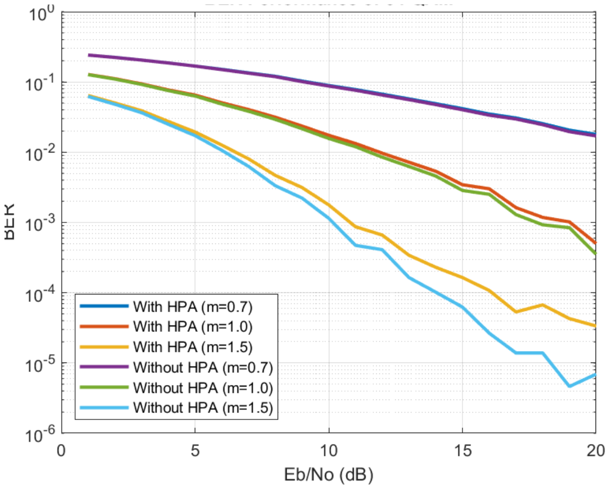

Fig. 8. BER performance of 64-QAM under various Nakagami channel

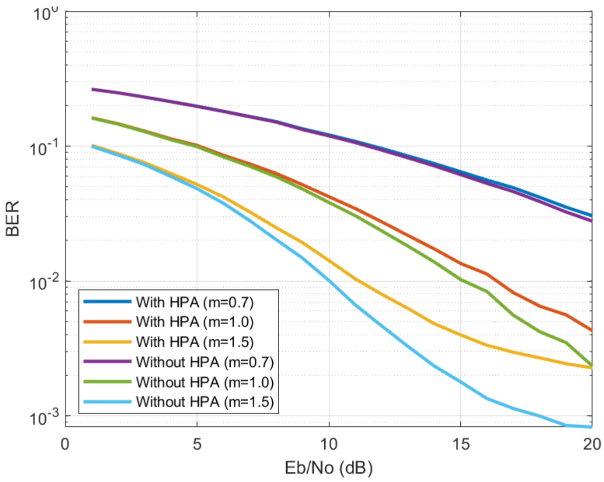

Fig. 9. BER performance of 256-QAM under various Nakagami channel

Fig. 10 shows the evaluation of 1024-QAM. Similar to the previous scenarios, both systems performed similarly at low *m*, and the difference between them got bigger as *m* was increased.

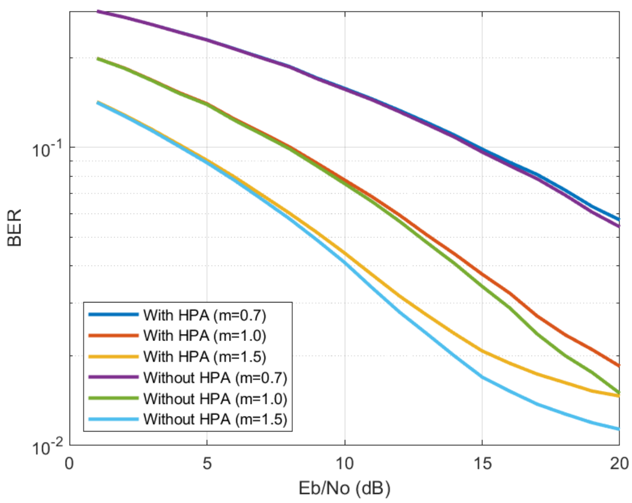

Fig. 10. BER performance of 1024-QAM under various Nakagami channel

Finally, the BER performance is to be compared between the conventional OFDM system and the one that has its PAPR reduced by PTS and Palm Date Leaf clipping. Both systems have similar HPA for each QAM, i.e., system with 16-, 64-, 256-, and 1024-QAM has the saturation level of 5 dB, 8 dB, 9 dB, and 11 dB, respectively. The comparison itself was performed under three Nakagami channels, i.e., *m* of 0.7, 1.0, and 1.5.

Fig. 11 shows the comparison for the systems that had 16-QAM implemented. Under Nakagami channel with *m* value of 0.7, both systems performed similarly. As *m* value was increased to 1.0, it was found that conventional system performed worse than the PAPR-reduced system, even thought the difference is almost negligible. As for Nakagami channel with *m* value of 1.5, the PAPR-reduced system performed better than the conventional one, especially for Eb/No value higher than 10 dB.

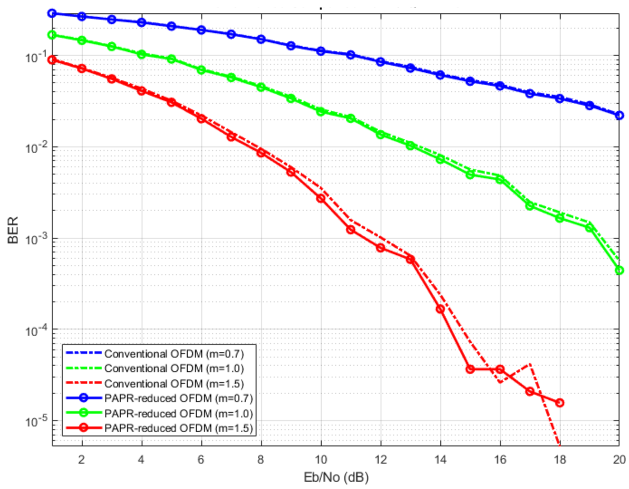

Fig. 11. BER performance comparison of 16-QAM

Fig. 12 shows the comparison for the systems that had 64-QAM implemented. Under Nakagami channel with low *m* such as 0.7, both systems were found to perform similarly. However, as *m* value was increased to 1.0, the conventional system performed better than the one that had its PAPR reduced. Even though the difference is relatively small, it can be seen at Eb/No value higher than 15 dB. As *m* value became higher, the conventional system performed better than the PAPR-reduced one at higher difference, especially for Eb/No higher than 10 dB.

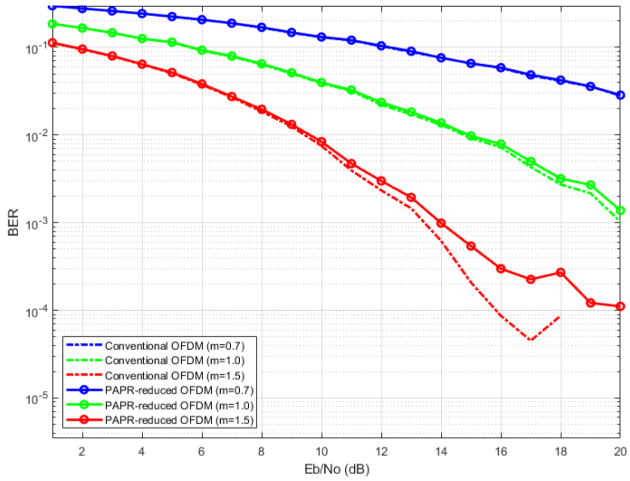

Fig. 12. BER performance comparison of 64-QAM

Fig. 13 shows the comparison for the systems that had 256-QAM implemented. In this case, the conventional system was found to have a better performance under all Nakagami channel. Furthermore, the difference got larger as *m* value was increased.

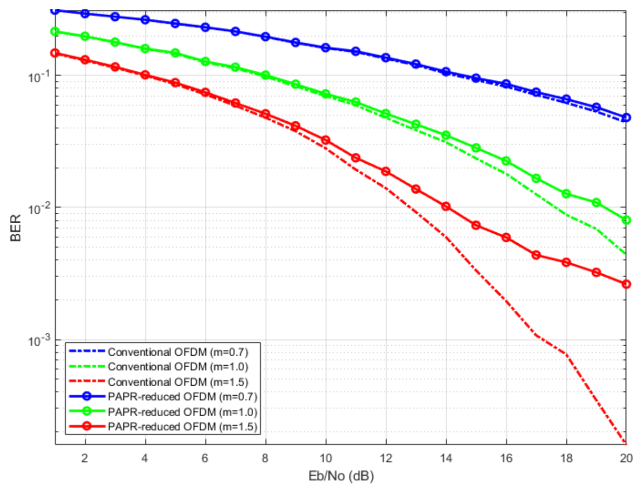

Fig. 13. BER performance comparison of 256-QAM

Fig. 14 shows the comparison for the systems that had 1024-QAM implemented. In this case, the conventional system was found to be better than the PAPR-reduced system. Under *m* of 0.7, the difference was noticeable at Eb/No value of 15 dB, while it was noticeable at Eb/No of 10 dB and 8 dB under Nakagami channel with *m* of 1.0 and 1.5, respectively.

Based on the results of BER performance, there are two things to be highlighted. The first one is the saturation level for different Nakagami channel, while the second one is the comparison to conventional OFDM system.

Previously, optimal saturation level was set according to the evaluation under *m* of 1.5. After evaluating various *m* values of Nakagami channel, it was found that the system required less saturation level at lower *m*, such as 1.0 and 0.7. For instance, 5 dB of saturation level is sufficient for *m* of 1.5 in system with 16-QAM. At *m* of 1 or 0.7, the system could use lower value such as 4 dB or 3 dB to get close to the ideal condition. As a note, Nakagami at higher *m* resembles channel with stronger LOS component. In this work, it is found that channel with stronger LOS component require higher saturation level of HPA to get closer to the performance under linear amplifier.

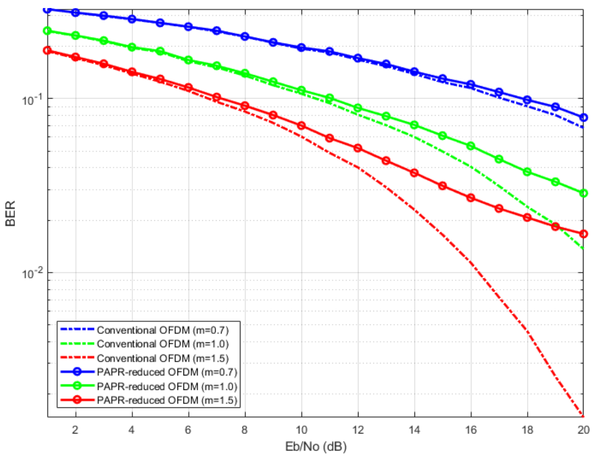

Fig. 14. BER performance comparison of 1024-QAM

Since the PAPR-reduced system has a clipping technique implemented in it, the BER performance is arguably worse than the conventional system. Even so, PTS technique compensated the distortion made by the clipping technique. Even though a different result was found at system with 16-QAM, the performance difference between conventional and PAPR-reduced system is very small. Here, the clipping did not distort the signal as significant as higher QAM level, thus making the performance under conventional and PAPR-reduced system to be similar.

V. Conclusion

To sum up, the simulation analyzed 16-, 64-, 256-, and 1024-QAM under various Nakagami channel. In addition, the HPA was also considered by using SSPA model. It was found that linear HPA serves as the lower boundary for non-linear HPA, and system under high saturation level performs similarly. In physical properties, high saturation level is equivalent to higher power consumption in amplifier. Thus, optimal level was obtained by considering taking the one with moderate BER performance. After the system's PAPR was reduced by PTS and PDL technique, the optimum saturation level of HPA was found to be 5 dB, 8 dB, 9 dB, and 11 dB for each QAM under Nakagami channel with *m* value of 1.5. However, this value was found to be ample for lower *m* value such as 1 or 0.7. In this case, the system required lower saturation level on the HPA for Nakagami channel with lower *m* value.

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